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Vapor Lock Resistant Fuel Systems for Forest Service Vehicles

U. S. Department of Agriculture, Forest Service   San Dimas Equipment Development Center

Equipment Development and Test Report 7120-2

VAPOR LOCK RESISTANT FUEL SYSTEMS FOR FOREST SERVICE VEHICLES

U. S. Department of Agriculture, Forest Service
Equipment Development Center, San Dimas, California 91773

MARCH 1971

Contents

List of Tables

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ABSTRACT

Fuel system malfunctions, such as vapor lock and hot stall, have, in the past, prevented full utilization of certain Forest Service emergency vehicles. This problem has been particularly acute on 300-gallon crew tankers.

The Forest Service Equipment Development Center at San Dimas, California, has developed a fuel supply system which should eliminate all such trouble. The system, which incorporates only readily available parts, was placed on one car, laboratory and road tested, and found to be completely satisfactory. It was then installed on three crew tankers in the California Region. All tests showed that fuel system malfunctions were completely eliminated. The cost of installation varies from $50 to $225, depending on the vehicle.

INTRODUCTION

Frequent fuel system malfunctions and failures have occurred on Forest Service vehicles, especially on fire tankers under emergency conditions. The four southern forests of the California Region documented 29 such failures between February 1960 and February 1966. Twenty-six of these failures occurred during the high fire hazard period, June through October. Traditional remedies seemed to have little effect on this situation. Figure 1 shows one such remedy, clothespins affixed to the fuel line.

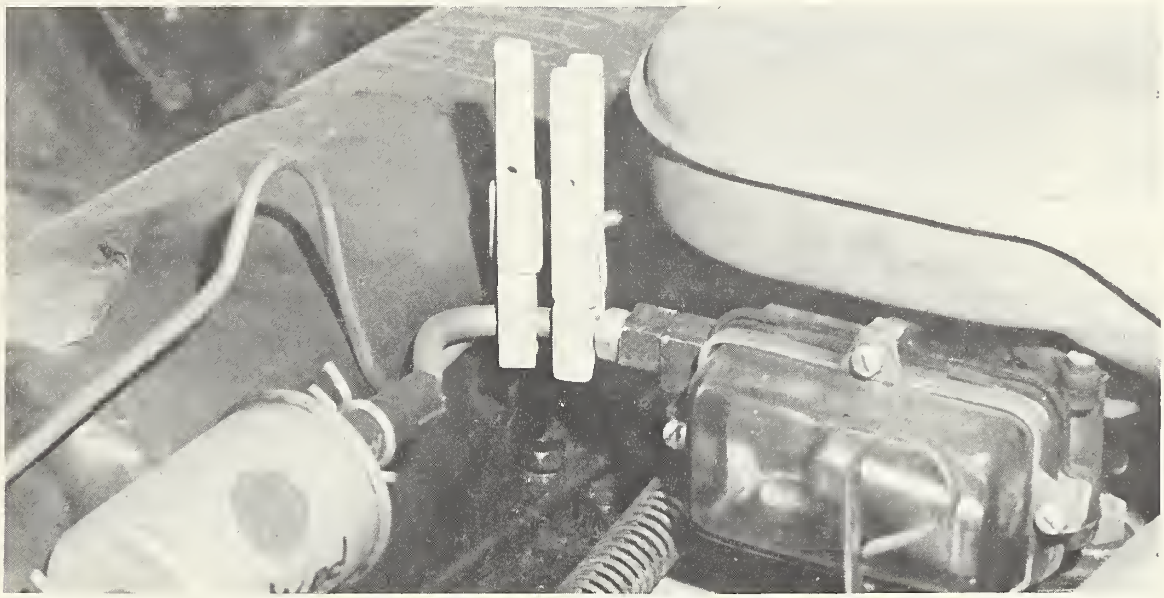

Figure 1. Clothespins used as heat sinks.

More sophisticated recent efforts have included use of louvered hoods and engine compartments, electric pumps installed as booster pumps, carburetor spacer blocks, and in-tank electric fuel pumps. Each of these has provided some degree of relief, but no combination has proven entirely satisfactory. Work carried out under ED&T 1512 and ED&T 1960 was intended to develop a more reliable fuel system than standard equipment.

DESCRIPTION OF FUEL SYSTEM MALFUNCTIONS

Three main types of malfunction occur with the standard engine-driven diaphragm fuel pump (fig. 2).

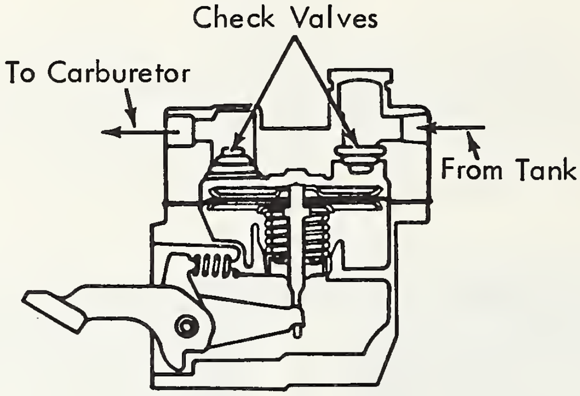

Figure 2. Standard engine-driven fuel pump.

The most common system malfunction is true vapor lock. This occurs when gasoline vaporizes in the pump or supply line, especially on the tank side of the pump. In this case, the pump cannot deliver to the engine an adequate supply of liquid fuel. Modern automotive fuel pumps are designed to pump a vapor-liquid mixture ratio as great as 30 to 1. However, since fuel vapor occupies a much greater volume than liquid at any given temperature and pressure, a vaporization of only 10 percent will cause the vapor-liquid ratio to exceed this limiting value. For standard gasoline this vapor-liquid ratio is exceeded at approximately 120°F. This varies greatly with composition (ref. 2).

The second malfunction is hot stall. This occurs when fuel boils in the line between the fuel pump and the carburetor, forcing liquid fuel to pass the carburetor float valve and to flood the engine. Hot stall is most common under soak conditions; that is, when the engine has been fully warmed up and then turned off. When hot stall appears under these conditions, hard starting is the result. Running hot stall can occur, however. The engine can be flooded due to vaporization of fuel in the fuel line while engine operation is taking place.

The third is mechanical failure of the pump. The symptoms are a rough running engine, missing, and backfire, quite similar to the effects of a number of other common engine ills, such as fouled spark plugs, a sticking carburetor float valve, etc. The most common pump failure occurs when the diaphragm either becomes ruptured or develops a small hole. In the case of a large rupture, the symptoms are obvious and immediate. The engine stops running because of an insufficient supply of fuel. However, if there is a pinhole in the diaphragm, this problem becomes quite difficult to diagnose.

If a fuel system could eliminate vapor lock, hot stall would also be eliminated. The work described in this report was intended to find ways to prevent these two malfunctions. No consideration is given to improving the reliability of mechanical fuel pumps.

PRELIMINARY INVESTIGATIONS

The San Dimas Center began investigating automotive fuel system failures in fiscal year 1963. A thorough market search and a literature analysis were made. More recently, ED&T Report 7130-1 (ref. 1) detailed the mechanism of vapor lock and other fuel system malfunctions and suggested remedial measures. The present report is an extension of the work done previously and describes efforts to utilize hardware modifications to eliminate fuel system malfunctions.

These preliminary investigations indicated that the following steps would be needed to perfect a system:

1. Test to locate troublesome areas in presently used fuel systems.
2. Determine how best to remedy the malfunctions in these areas.
3. Determine what hardware modifications would most economically achieve satisfactory remedies.
4. Synthesize the hardware modifications into a system concept and test to determine its effectiveness.
5. Once an effective system concept has been found, install the hardware on vehicles for actual field tests.

TEST PROCEDURES

The first step in this program was to determine temperatures and pressures at various locations in a standard fuel system under dynamometer and road operation. For this, a 1962 Ford 6-cylinder sedan was used, because of its history of fuel system malfunctions. Pressure sensors were placed at the inlet and outlet of the mechanical engine-driven fuel pump. Gasoline temperatures were taken at the fuel tank, inlet and outlet of the fuel pump, inlet of the carburetor, and in the carburetor float bowl. Figure 3 shows the fuel system and the areas which were monitored during the tests.

Exhaust pipe "first bend" temperature, oil temperature, under-hood air temperature, and manifold vacuum were monitored in order to insure that engine operating conditions remained relatively constant from test to test. All engine and fuel system data were continuously recorded on a CEC 5-124A oscillograph. For road testing, a Honda E-300 portable generator provided instrument power. No attempt was made to simulate the hot road surface on dynamometer tests. Air-fuel-ratio change at the onset of fuel system malfunction was not recorded because the slow response of commercially available air-fuel meters makes such data meaningless.

Dynamometer testing was carried out by utilizing a driving cycle similar to that used by the Cooperating Research Council for their road tests of 1962 and 1964 (ref. 3) and took place on a Clayton CT-200 dynamometer equipped with an inertia flywheel. Vehicle cooling was provided by a Chelsea PLDUP 300 fan. This cycle was as follows:

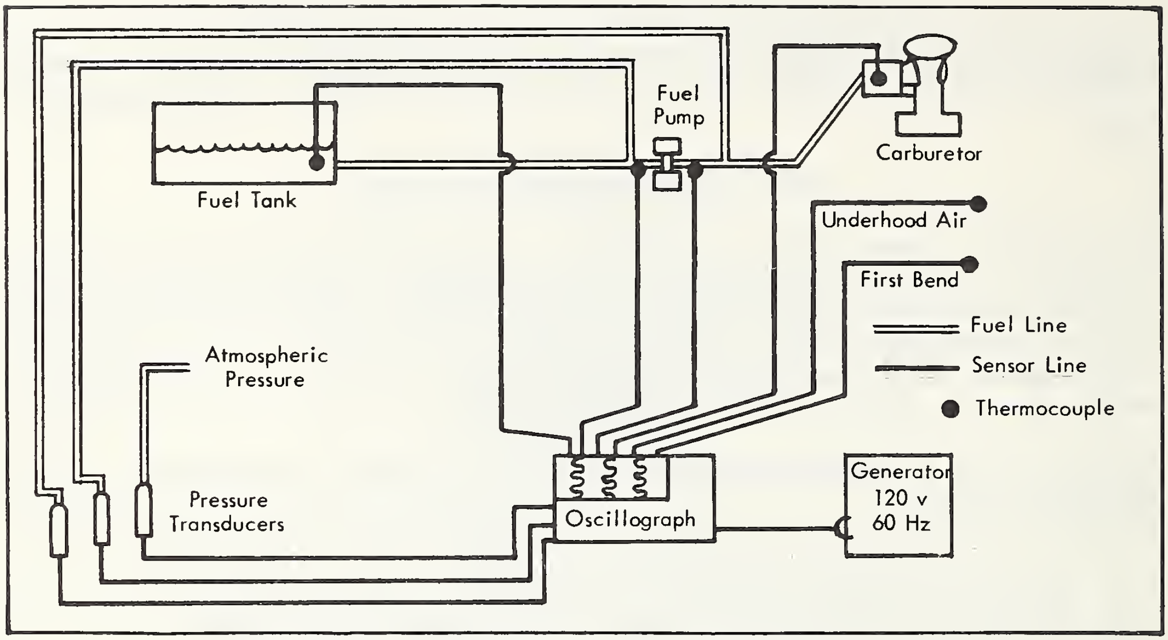

Figure 3. Fuel system evaluation test setup.

1. Two 15-60 mph (high gear) timed "base" accelerations. The hydraulic absorption unit of the dynamometer was set to 10 road hp at 35 mph to simulate road load. The inertia flywheel was engaged to simulate vehicle inertia. These accelerations were used as a basis of comparison to evaluate acceleration times later in the cycle. Following the accelerations, the maximum horsepower of the vehicle was determined.

2. Ten minutes of 10 hp, 35 mph, 2nd gear operation. This approximates the 10 minutes of 60 mph of the CRC procedure. Second gear was used to preserve rear tires.

3. Fifteen-minute engine-off soak.

4. Repeat the accelerations and maximum power run of step 1. Any increase in acceleration time or decrease in maximum horsepower is an indication of fuel system malfunction.

5. Five minutes of the mode of step 2, to restabilize engine conditions.

6. Ten-minute idle soak. Cooling fan is off.

7. Repeat step 1.

The repeatability of the base (step 1) acceleration times was found to be ± 10 percent, if no vapor lock occurred. Ambient temperature, which has a marked effect on results, was kept at 100 °F ± 10 °F for all dynamometer runs. Dynamometer testing revealed that incipient vapor lock could be detected - before engine performance was degraded - by close monitoring of the fuel pump output pressure. When liquid fuel only was being pumped, the output pressure remained nearly constant. As an increas-

ing volume of vapor was delivered, the width of the fuel pump trace on the recorder (that is, the variation in output pressure) became greater and greater until the pump output pressure was varying approximately 2-1/2 psi peak to peak, at which time engine operation was not possible at full load. It should be noted that the mean pressure remained nearly constant despite the high vapor-liquid ratio being delivered.

Road testing was carried out on Interstate Highway 15 in San Bernardino County, California, running north from Devore Road to Cajon Summit. This is a 4-lane divided freeway on which the maximum legal speed (65 mph) may be safely maintained. The last 3-1/4 miles (grade approximately 6 percent), on which the car's manifold vacuum averaged 8 inches Hg, was considered to be the test section. From Devore Road to this point, a distance of 15 miles (average manifold vacuum - 13 inches Hg) was considered to be warmup. A speed of 50 mph, in high gear, was maintained during both warmup and test.

Since it was impossible to have vapor lock repeatedly by using commercially available fuel, it was induced by using a special technical fuel with a Reid Vapor Pressure (RVP) of approximately 15 psi. (Table 1 gives its physical properties.) Commercially available gasoline has an RVP of about 9 psi in summer; about 12 psi in winter. RVP, while not an absolutely reliable measure of vapor-forming ability, does provide an easily performed and repeatable check on the vapor-forming characteristics of gasoline.

TABLE 1

PHYSICAL PROPERTIES OF HIGH VAPOR LOCK TECHNICAL FUEL

Reid Vapor Pressure (RVP)	14.5 psi
API Gravity, °API	73.0
Octane Number, F-1	100.8
Initial Boiling Point:	78 °F
5% Point	98 °F
50% Point	196 °F
End Point	358 °F

ISOLATION OF PROBLEM AREAS

Table 2 shows average gasoline conditions obtained from running the car on the dynamometer under severe ambient conditions for the various fuel system configurations tried. Each run listed is the worst vapor lock condition obtained during the test run. In all cases, this was cycle 4 or 7 (see Test Procedures, p.4). From table 2, run (1), it can be seen that the worst conditions for gasoline heating exist in the mechanical fuel pump (32°F Rise) and in the line between the fuel pump and the carburetor, (33°F Rise).

Table 3 shows the results of the road tests. This test was less severe than the dynamometer test. There is no significant gasoline heating in the mechanical fuel pump. This is because engine block temperature is lower during road operation than during dyno operation. Note that there is, however, significant fuel heating between the fuel pump and the carburetor, just as there was during the dynamometer tests.

It is significant that gasoline temperatures obtained during tests with standard gasoline and the special technical fuel were substantially the same for identical operating conditions. This indicates that results obtained using the technical fuel are applicable to situations in which standard gasoline is used. At any given temperature the technical fuel had a much higher vapor-liquid ratio. Temperature measurements taken during runs using the standard engine-driven fuel pump (table 2, run (1)) indicate that vapor lock occurred when the vapor-liquid ratio was approximately 20:1 at the fuel pump.

Summarizing, then, the first step of the test: By using a special fuel, vapor lock was obtained repeatedly and reliably, under both road and laboratory conditions. It was determined that fuel system temperature and pressure were not affected significantly by the fuel's vapor-forming ability. The fuel system areas most likely to respond to corrective treatment were determined to be (1) mechanical fuel pump, and (2) fuel line between pump and carburetor float bowl.

Table 2.--Summary of dynamometer test results (ambient atmospheric temperature 100°) ± 10° F

			Most severe vapor lock condition gasoline temperature, °F ± 15 °F						
Run number	Fuel system	Fuel	Tank	Pump inlet	Pump outlet	Fuel line at firewall	Carburetor inlet	Carburetor bowl	Vapor lock severity (degradation of acceleration time)
(1)	Standard engine-driven diaphragm pump	Regular	97	105	137	--	--	170	Incipient
		Tech.[1/] fuel	80	100	130	--	--	156	Complete
(2)	Standard engine-driven diaphragm pump Fram filter bypass	Regular	77	95	121	--	146	156	None
		Tech.[1/] fuel	84	105	134	--	141	151	40%
(3)	Single Bendix electric pump at tank	Regular	85	85	90	105	--	155	Incipient
		Tech. fuel	90	90	95	105	--	145	Complete
(4)	As (3) above, plus Fram filter bypass	Regular	75	75	75	90	100	140	None
		Tech. fuel	85	85	78	95	110	135	20%
(5)	As (4) above, plus radiant heat shield	Tech. fuel	80	80	78	83	115	145	20%
(6)	As (5) above, plus carb. spacer block & rerouted fuel line	Tech. fuel	95	95	85	85	110	125	10%

1/ Average of 2 runs.

Table 3.--Summary of road test results

Run number	Fuel system	Fuel	Ambient air temp., °F wind, mph	Gasoline temperature, end of test section °F ±5°F					Vapor lock
				Tank	Pump inlet	Pump outlet	Fuel line at firewall	Carburetor bowl	
(1)	Standard fuel pump	Regular	86/5-15	77	95	95	95	115	No
		Technical	89/5-15	85	85	95	95	105	Yes
(2)	Bendix pump, Fram bypass	Regular	80/10-20	95	95	90	85	100	No
		Technical	80/10-20	85	85	85	85	98	No

DEVELOPMENT OF AN IMPROVED FUEL SUPPLY SYSTEM

Once the trouble areas were isolated, the next step was to develop a fuel system which was not prone to vapor lock or hot stall malfunction. The area of first attack was the mechanical fuel pump. The initial approach was to install a Bendix electric fuel pump at the gasoline tank. This removed the pump from the hot engine block and also put the entire fuel line under positive pressure. Thus, a higher fuel-line temperature could be tolerated without vapor formation. Performance was greatly improved, but vapor lock was still experienced when using the technical fuel. Tables 2 and 3 show severity of vapor lock obtained with various fuel supply systems. Under full load dynamometer operation, vapor bubbles were observed in clear sections which had been inserted in the fuel line and the gasoline float level was observed to be below normal. (See figures 4 and 5.)

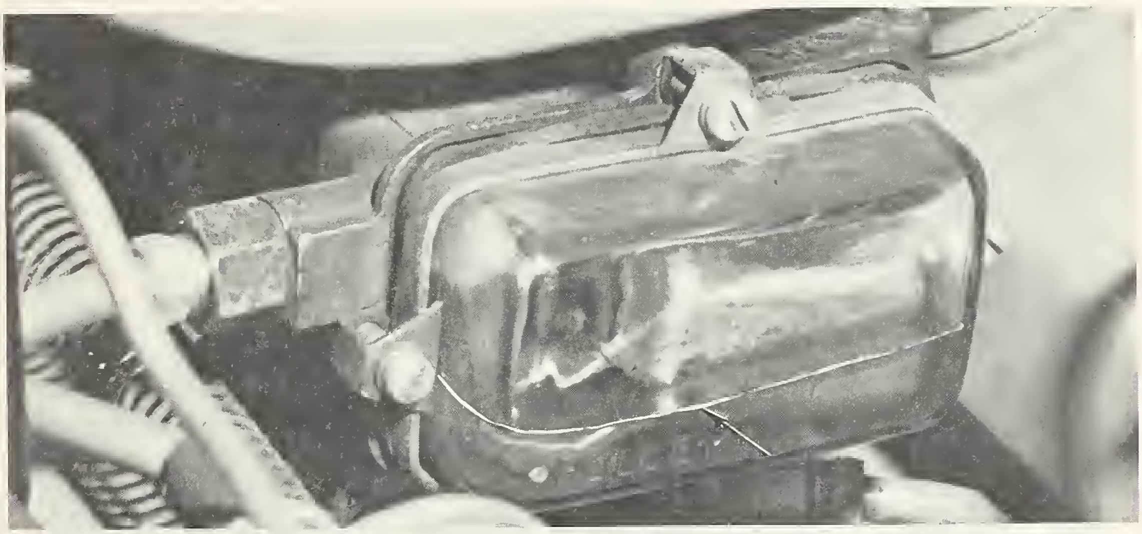

Figure 4. Carburetor float bowl during vapor lock.

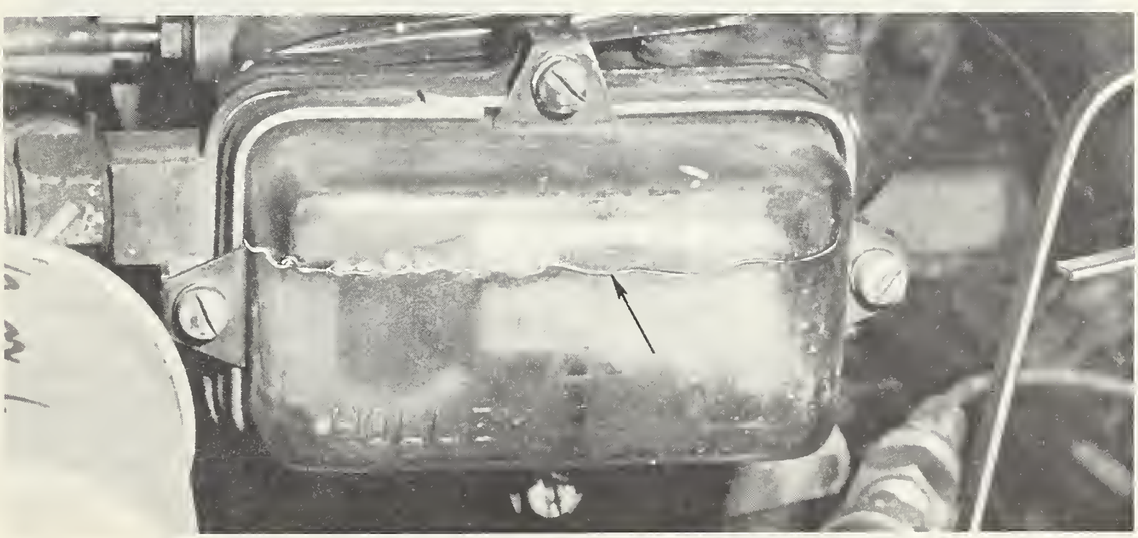

Figure 5. Same carburetor float bowl under normal conditions.

This was an indication of vapor lock; that is, that the pump could not supply enough liquid fuel to satisfy the full load requirements of the engine. Temperature measurements indicate that approximately 8 percent, by weight, of the technical fuel had vaporized in the fuel line by the time it had reached the location where the fuel line entered the engine compartment. Only 70 percent, by weight, remained liquid in the float bowl. (These percentages were calculated from the technical fuel's distillation curve and the data from run 3). This last condition represents a vapor-liquid volume ratio of about 70 to 1.

The next approach was to install a return line to the gasoline tank near the carburetor to serve as a bypass and pressure vent. A Fram in-line fuel filter (Model G-18), such as is used on air-conditioned late model Pontiacs, was utilized. Figure 6 shows this device installed on another vehicle.

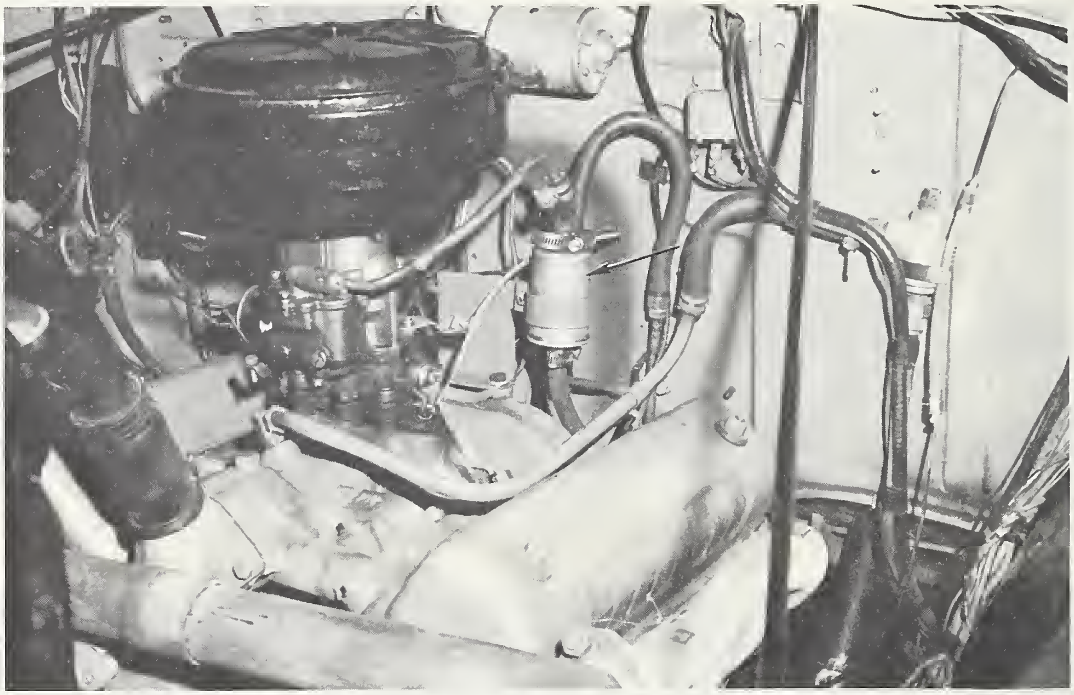

Figure 6. Fram G-18 filter in recirculating system.

With gasoline at 72 °F and a supply pressure of 10 in. Hg, approximately 50 percent of the total flow is returned to the fuel tank when the flow to the carburetor is 10 gph, which approximates maximum full-load fuel consumption for a truck engine of the 300-cubic-inch class. The orientation of the filter is such that any vapor formed in the fuel line is vented to the gasoline tank. This system virtually eliminates the possibility of hot stall. Performance was improved to the point that there was only slight vapor lock, even using the special technical fuel, under the severest dynamometer test conditions. The effect of the bypass is to reduce the fuel temperature by reducing its residence time in the pump and fuel line. Gas tank heating from returned fuel was determined to be negligible, less than 15 °F in the worst case.

The reduction in RVP, due to the evaporation of lighter portions of the gasoline on return to the tank, was not considered serious. In fact, this improves the hot weather performance of the fuel system. The reduction in effective miles per gallon caused by the loss of these light portions has not been measured, but should not be serious.

From the distillation curve of normal summer grade gasoline, a 5 percent loss in mileage is the most that would be expected, based on temperature measurements taken in the return line at the gasoline tank. The bypass was tried with both electric and original equipment engine-driven diaphragm fuel pumps (table 2, runs 2 and 3). The electric fuel pump showed slight improvement over the standard pump.

In order to further reduce vapor locking tendencies, three more fuel system modifications were tried: (1) A radiant heat shield of 16-gauge aluminum was installed; (2) An insulating block made of 3/4-inch marine plywood was placed between the carburetor and manifold; (3) The fuel line, from where it enters the engine compartment to the carburetor, was re-routed to reduce heat absorption. The first two of the three improvements are shown in figure 7. From table 2 it can be seen that the most effective of these modifications is the carburetor spacer block and the re-routing of the fuel line. Both have the effect of removing the carburetor and fuel line from immediately adjacent heat sources. Note, from table 2, run (6), that the carburetor float bowl temperature is significantly lower than that of previous runs, while the carburetor inlet temperatures are about the same. The radiant shield did not reduce carburetor bowl temperature.

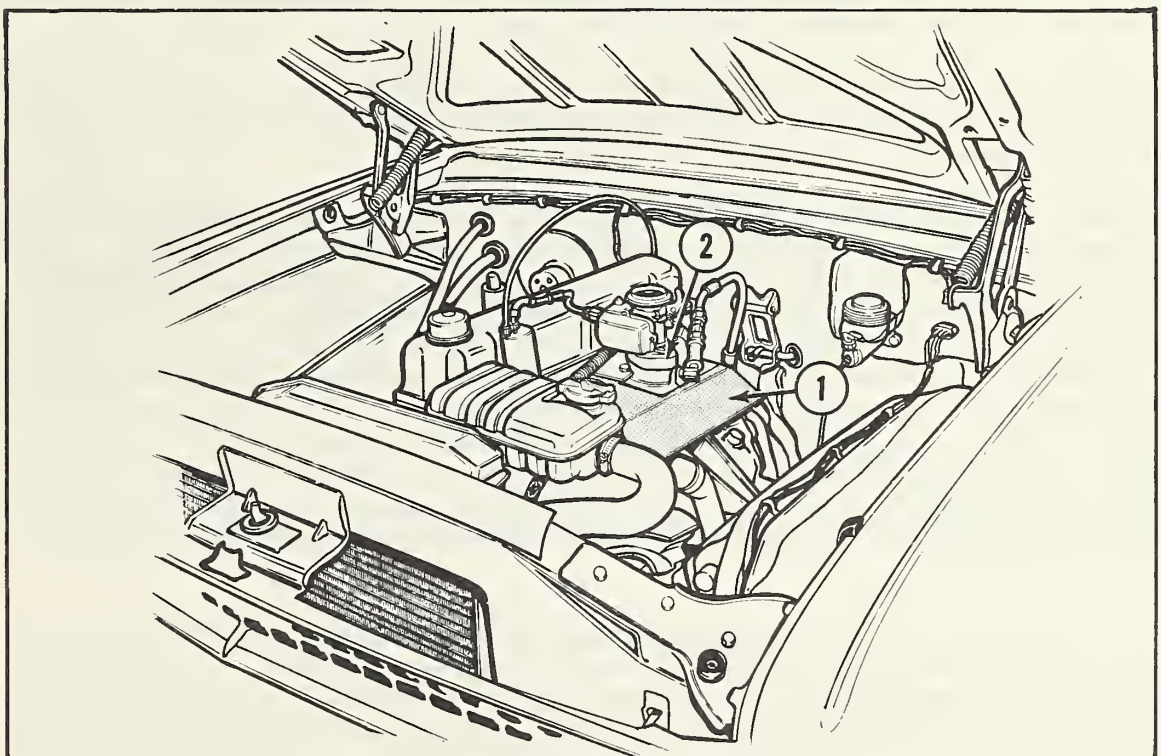

Figure 7. Radiant heat shield (1) and insulating block (2).

FUEL PUMP CONSIDERATIONS

From the test work described above, it became obvious that an electric fuel pump might be an important part of the final vapor lock resistant fuel system. Therefore, determination of performance characteristics of commercially available pumps was necessary. Since most pump manufacturers do not supply these figures, tests were run to determine them.

ELECTRIC PUMPS

Electric fuel pumps, such as those used in the improved fuel supply system described in figure 7, are designed to work against a pressure of about 8 inches Hg and with a maximum delivery of between 10 and 40 gallons per hour. In a recirculating fuel supply system the pressure is lower, about 5 inches Hg, and the delivery is approximately twice as much. Since all the fuel pumps considered for use in this project are of the positive displacement type, this means twice as many strokes or rotations with twice the wear. Since the wear encountered in these electric fuel pumps is usually negligible, even after hundreds of thousands of miles in normal service, it is not expected that any pump life problems will be encountered. Six different manufacturers are represented in prototype fuel supply systems installed on three California Region crew tankers. These prototype fuel systems are discussed in further detail later in this report.

Each fuel pump was bench tested to determine its flow, its maximum current requirements, and its cutoff pressure before it was installed. Table 4 shows the results of these tests and also the basic type of the fuel pump.

Figure 8 shows the delivery versus pressure curves for the six pumps tested. Only AC and Carter pumps show the performance necessary for satisfactory operation of the fuel supply system.

Delivery (flow) is the most important parameter to consider in selecting a pump. Delivery pressure of 6 inches Hg was selected from figure 8 to prepare table 4. This coincides with the maximum fuel pump output observed in the remedial fuel system. Because a certain amount of the gasoline delivered by the fuel pump will never reach the carburetor due to vaporization, an excess capacity is necessary. Under maximum load conditions, a tanker with a 325-cubic inch engine might require up to 20 gallons of fuel per hour. With normal summer grade gasoline and a carburetor inlet temperature of 150 °F, approximately 30 percent of the fuel will be vaporized. (Most of this vaporized fuel condenses on its return to the fuel tank.) Thus, to be safe at 150 °F, an excess delivery of 6 gph (30% of 20) is necessary. A small return flow of liquid fuel, in addition to vapor, is required to maintain a positive head at the carburetor.

Cutoff pressure is also an important parameter. This is the pressure at which the fuel pump delivery falls to zero. An ideal pressure-flow curve would be flat at the maximum flow and then drop off to zero abruptly at approximately 9 or 10 inches of Hg. If the pressure exceeds approximately 15 inches of Hg, there is danger the fuel pump output pressure will overcome the carburetor needle valve, thus flooding the carburetor.

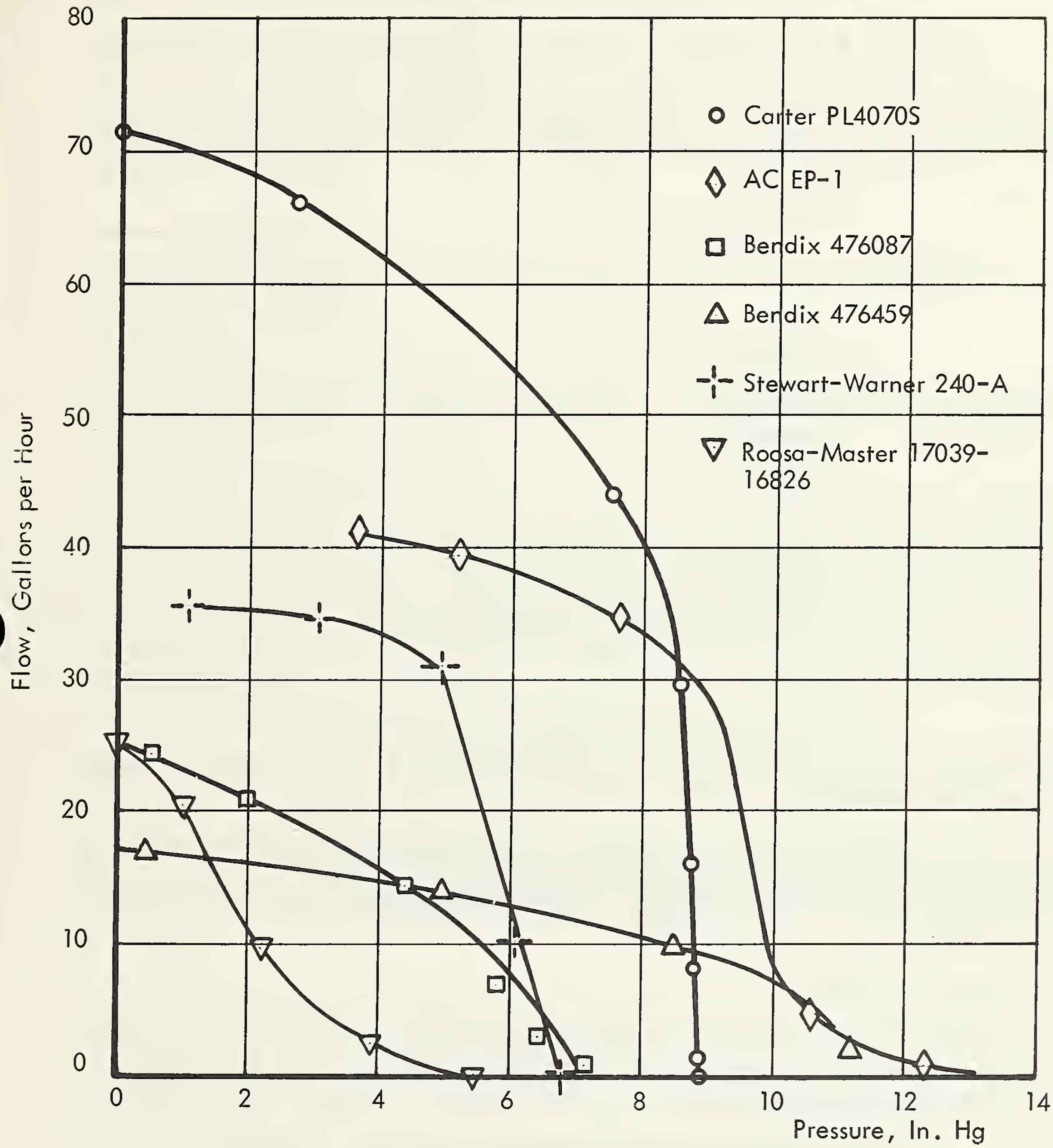

Figure 8. Fuel pump performance.

Table 4.--Fuel pump characteristics

Manufacturer and model no.	Type	Delivery at 6" Hg, gph	Cutoff pressure in.Hg	Max. current drain*amp.	Built-in filter?
Bendix 476 459	Solenoid-plunger	13	11	0.8	Yes
Bendix 476 087		8	7	0.7	Yes
AC EP-1	Motor-diaphragm	38	13	2.1	No
Roosa Master 17039-16826	Solenoid-diaphragm	0	$5\frac{1}{2}$	1.4	No
Stewart Warner 240-A	Solenoid-plunger	13	7	4.2	Yes
Carter PL4070S	Rotary vane	53	9	3.3	Yes

* All 12 VDC

The pressure cutoff in all of the pumps tested is accomplished by a calibrated bypass valve in the fuel pump.

Maximum current drain is also important as this predicates the size of wire necessary for the pump. If the current drain is excessive, one could expect to have to increase the truck's electrical system capacity. This was not considered necessary for any of the pumps tested.

MECHANICAL PUMPS

The addition of a bypass does not affect the operation of a mechanical fuel pump. Air-conditioned General Motors cars, which utilize a bypass in the fuel supply system, use the same fuel pump as similar models which do not have a fuel bypass.

FIELD TESTS AND SURVEILLANCE OF IMPROVED SYSTEMS

Three system designs utilizing electric pumps were installed on three California Region 300-gallon (Models 56 and 60) crew tankers. All were identical in concept but differed in construction details. One system using the stock mechanical pump was

installed on a nurse tanker. These installations were not intended to represent final system configurations, but were for test purposes only.

Dynamometer tests, similar to those described above under "Test Procedures" were carried out at 100°F ambient temperature and full load conditions on the three crew tanker systems. Using the special technical fuel (see table 1), these tests revealed that all systems were completely effective in eliminating vapor lock and hot stall. The mechanical pump system was not dynamometer tested, but road tests showed no fuel system difficulties.

The surveillance of the three crew tanker fuel supply systems was continued throughout one fire season. Operators of all three trucks were instructed to report any malfunctions to the Project Engineer immediately so that these could be studied and further occurrences prevented.

Each of the systems is described below, and the results of the field tests and surveillance of each are given. Based on these results, an optimized system was designed and it is presented in the "Recommendations" section of this report.

GENERAL DESCRIPTION OF SYSTEMS

In each of the three crew tanker systems, electric fuel pumps (one or more) were mounted at each tank. These were placed as close to the tank and as low as practical. This was done to keep as high a head on the inlet side of the pump as possible. Only one pump (or the pumps for one tank) was operated at any given time. One system utilizing a mechanical pump was installed on a nurse tanker - see section entitled "Improved Mechanical System".

Mechanical pumps were not used on the crew tankers for three reasons:

1. The system using electric pumps was shown to perform better (see table 2).

2. Mechanical pumps do not have the record of reliability that electric pumps do.

3. On a vehicle with dual gasoline tanks, some method is necessary to switch the return gasoline line. One pump for each tank makes it possible to do this automatically.

Where necessary, the output of the pumps went through check valves to prevent the pump for one tank from forcing fuel back through the other pump into the other tank.

From the check valves, the fuel lines ran to a tee, then to the inlet of the bypass arrangement (Fram G-18 filter). The main outlet of the bypass went to the carburetor; the return outlet went to a switching device and then back to the fuel tank. The tankers on which the systems were installed each had two tanks; so some provision was necessary to insure that fuel was returned to the same tank from which it was taken.

In all systems, 3/8-inch cadmium plated mild steel tubing was used for the fuel line; 5/16-inch tubing would have been equally satisfactory, as well as being much more

convenient and easier to work with. It is important that no copper tubing be employed in the fuel system. It is more prone to failure through vibration, and copper acts as a catalyst for gasoline gum formation. Imperial Eastman brass "compression" fittings were employed at all junctions. Compression fittings were chosen because the necessity to flair the tubing is thus eliminated. Whenever a transition from frame-mounted hardware to engine-mounted hardware was made, Imperial Eastman No. B706 3/8-inch i.d. hose was used. The appendix gives detailed parts lists for each of the system installations. In all cases, Fram G-18 in-line fuel filters were used for bypass (fig. 9).

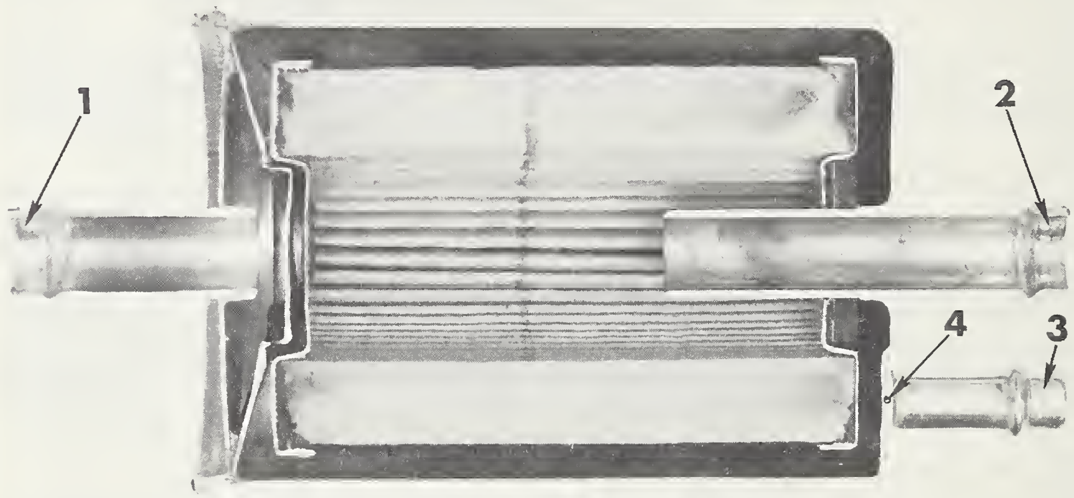

Figure 9. Fram filter, showing construction details - inlet (1), outlet to carburetor (2), return to tank (3), and orifice (4).

Imperial Eastman B706 hose and spring-type clamps were employed to connect the Fram filter to the lines. The filter was mounted in an upright position and provided with a mounting bracket. (See figure 6.) Most major filter manufacturers offer models equivalent to the G-18. Great care was taken to place all lines and other components as far from heat sources as practicable. Figure 10 shows how the return line was affixed to the gasoline tank. (Caution - Do not weld to fuel tank without reference to Forest Service "Health and Safety Code" 6-71.) Although no carburetor spacer blocks were used in the three improved systems tried, these blocks are available for most vehicles from dealers and could be included at modest cost in any vapor lock resistant fuel system.

Figure 10. Method of affixing return line to gasoline tank.

SYSTEM 1 - MANUAL RETURN LINE SWITCHING

System Description

The first improved system, shown in figure 11, utilized a manual valve to determine to which tank the return gasoline was routed. This system was installed on FS 2109, a 1955 Ford 300-gallon crew tanker. Although entirely satisfactory functionally, this system had several shortcomings. The first of these was that the internal check valves of the fuel pumps were not 100 percent tight; that is, when one bank of pumps was activated, leakage through the other bank caused the tank from which fuel is not being pumped to fill. This could have led to a dangerous overflow condition. To overcome this, subsequent systems utilized some form of external check valve.

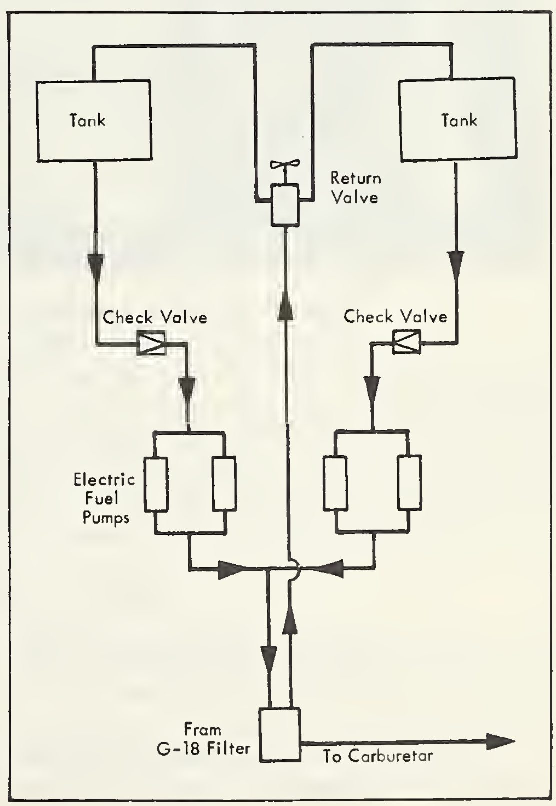

Figure 11. Prototype fuel system 1 as installed on Model 56 tanker.

Also, it was felt that the manual return valve was likely to be overlooked by the operator since its use is not required to switch feed lines. This could have led to quick flooding of one tank.

Figure 6 shows the Fram fuel filter and its bracket in place. Compare the location of the gasoline feed line with that of the stock system, figure 12. The practice of locating fuel lines near hot engine parts, especially manifolds, is a well-established cause of vapor lock (ref. 4).

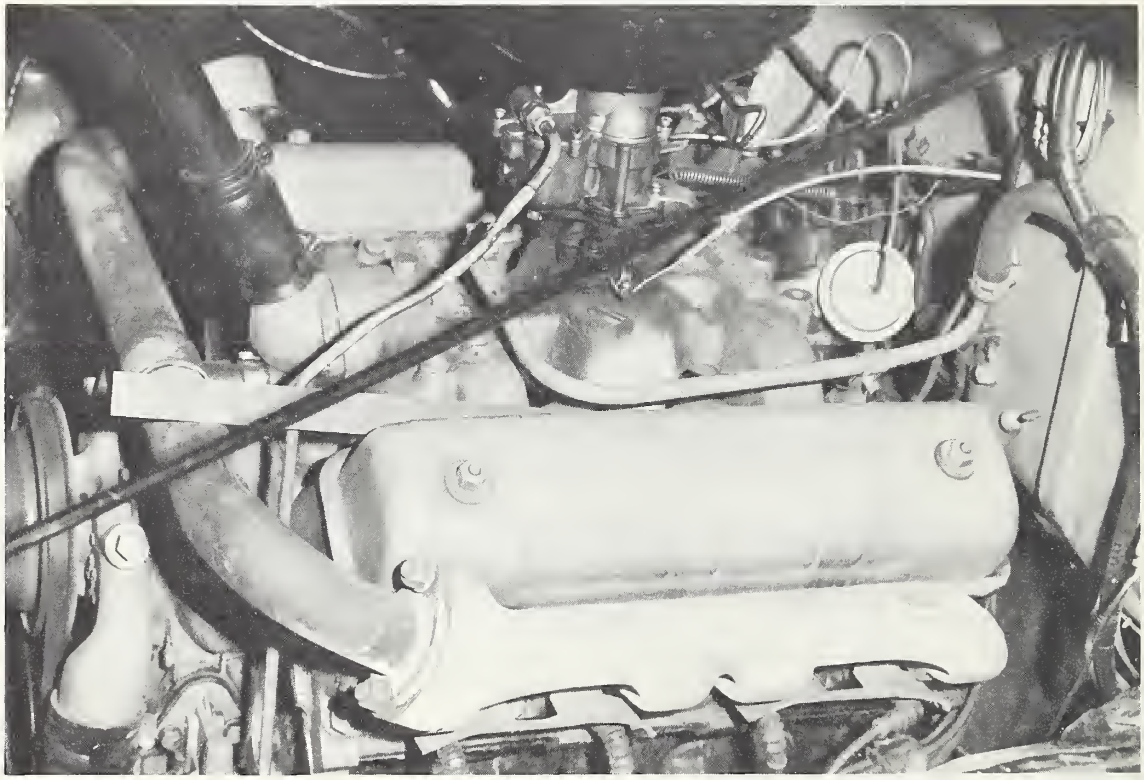

Figure 12. Stock routing of gasoline line for FS 2109.

Four pumps are used in this setup, shown in figure 11. The pumps are arranged so that for normal use only one pump is running at any given time. If the vehicle operator thinks that fuel system malfunction (vapor lock) is imminent, he can energize the second pump for the same tank. Both tanks cannot be pumped down at once. This multiple pump arrangement is for test purposes only; it is unlikely that a dual pump (per tank) system will be needed with the AC or Carter pumps.

Field Test Results - System 1

This system suffered three failures during the surveillance period, which involved a total of 2,250 miles and 13 months.

1. One of the Circle Seal check valves was stuck in an open position. This could lead to the dangerous situation of flooding one gasoline tank. These check valves,

although of an extremely high quality, are not designed for use in contaminated systems.

2. One of the gasoline hoses, an unbranded type used in one location on this tanker, had cracked to a point where it was unusable. The Imperial Eastman hose showed no signs of aging or weather checking.

3. A pumper engine fuel line failed. (This truck is equipped with an engine-powered pumper (not PTO).)

It was originally felt that fuel should be supplied at positive pressure to the pumper engine so the fuel line to the pumper engine had to be taken from the carburetor side of the main fuel system pumps. When the fuel line to the pumper engine broke, all of the gasoline in the main tanks was pumped out, resulting in a serious fire hazard and the loss of use of the tanker. Since the pumper engine had its own fuel pump, the line which supplies it was relocated to the inlet side of the fuel pump.

The emergency capability of this system - that is to run both fuel pumps at either tank - was never used during the season. Therefore, it was decided to revise the entire system to eliminate some of its complexity. The improved system, number 1, shown in figure 13, utilizes only one AC electric fuel pump and a stacked manual valve. Use of this valve eliminates the need for check valves. The valve, a Conant model BR2TSL, is shown in figure 14. This system should provide the greatest simplicity and reliability of operation.

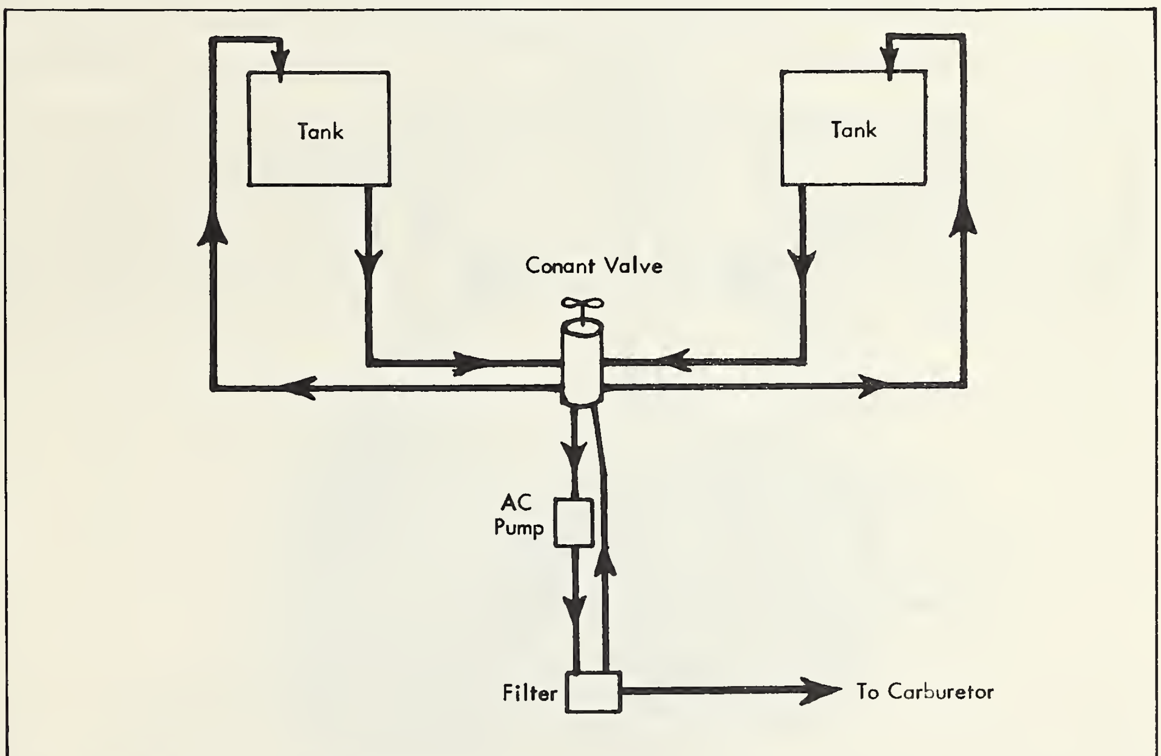

Figure 13. Fuel system number 1, improved.

After the test, each of the pumps was retested. The Bendix pump, Model 476087, showed no deterioration but was of a capacity deemed insufficient. The Stewart-Warner Model 240-A and the AC Model EP1 showed only slight deterioration. The Roosa-Master Model 17039-16826 showed a deterioration of its already unacceptable pumping capacity.

Figure 14. Conant Model BR2TSL valve.

SYSTEM 2 - AUTOMATIC FLUIDIC RETURN LINE SWITCHING

System Description

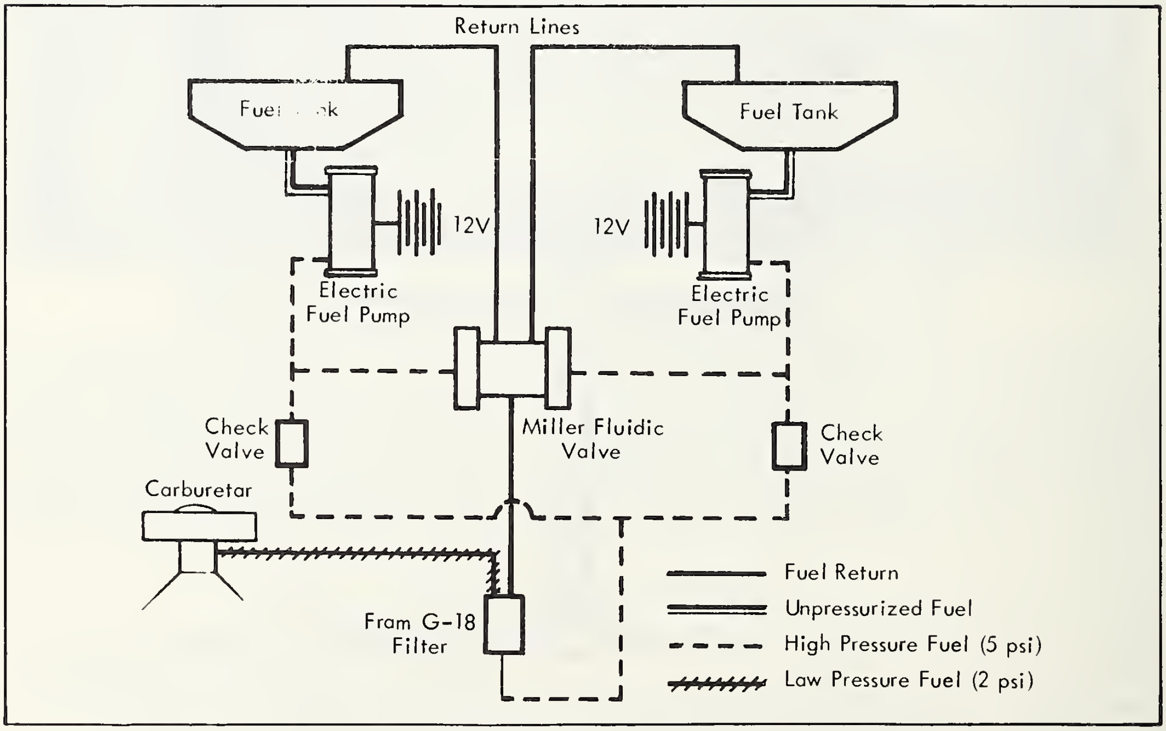

Figure 15. Prototype fuel supply system 2 as installed on Model 60 tanker.

The second system (fig. 15) utilized check valves and a Miller fluidic bonnet return valve. Carter fuel pumps, which are rubber mounted and have an internal filter, were used. In this system, fuel pump pressure automatically switched the return gasoline flow to the proper tank. The Circle Seal type 119B2PP check valves used proved to be 100 percent tight at any pressure encountered and have a very low pressure drop in the normal flow direction. This system had the advantage of simplicity in that no operator effort is required to switch the return lines when the gas tank to be used is changed. However, component failures have been encountered. Gas tank changing was accomplished by a single switch on the dash, which also switched the gas level gauge. This system was initially installed on the Center's prototype model 60 tanker (FS 2032).

Field Test Results - System 2

This system, as originally tested, was definitely unsatisfactory. The Miller fluidic valve was found to be unsuitable for gasoline service. The spool stuck and, even though made of Buna N, the diaphragms became swollen and ripped. The fluidic valve was replaced with a Circle Seal type 459B2PPP shuttle valve. These valves are shown in figures 16 and 17.

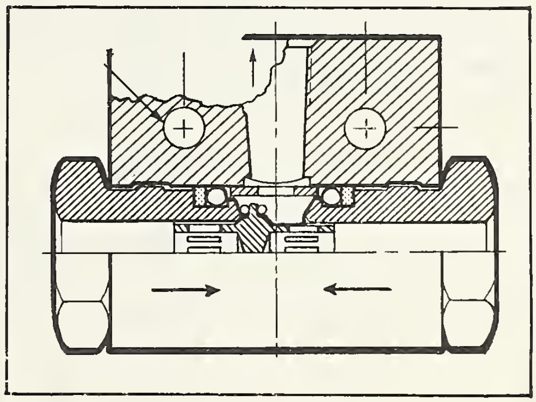

Figure 16. Circle Seal type 459B2PPP shuttle valve.

This Circle Seal valve, which is operated by differential pressure in the return line, would also have provided automatic return switching. It was, however, found to be too sensitive to the attitude of the tanker to provide positive return switching. It was replaced with a Skinner V53 solenoid valve. This in effect converted the system to the "system 3" configuration (see fig. 18). After the Skinner valve was installed there were no further difficulties and the tanker was placed in the field. The surveillance period of one year covered 2,500 miles. After this time all components of the

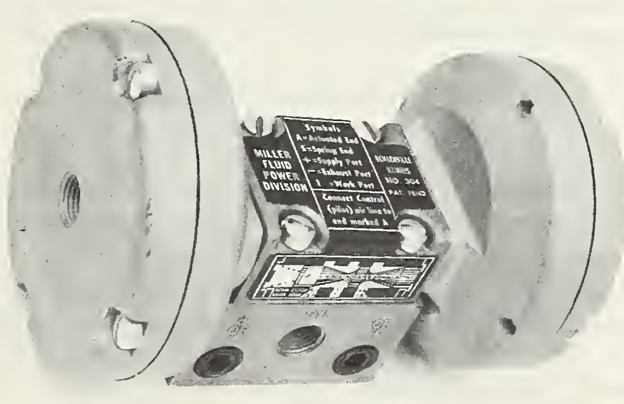

Figure 17. Miller fluidic valve.

fuel system were inspected and found to be in good working order. Both Carter pumps were tested and found not to have deteriorated in performance.

This tanker responded to 55 emergency calls during the surveillance period. Not one fuel system malfunction was experienced.

SYSTEM 3 - ELECTRIC RETURN LINE SWITCHING

System Description

The third system (fig. 18) employed a Skinner V53 solenoid valve. This valve was activated by the same switch as the fuel tank gauges, and drew only 0.8 amps when energized. The pumps were activated by the same switch. Circle Seal check valves were utilized in this system also. This third system had the same advantage of operator simplicity as the second and is considerably less expensive. FS 1609, a Model 56 tanker, was fitted with this system.

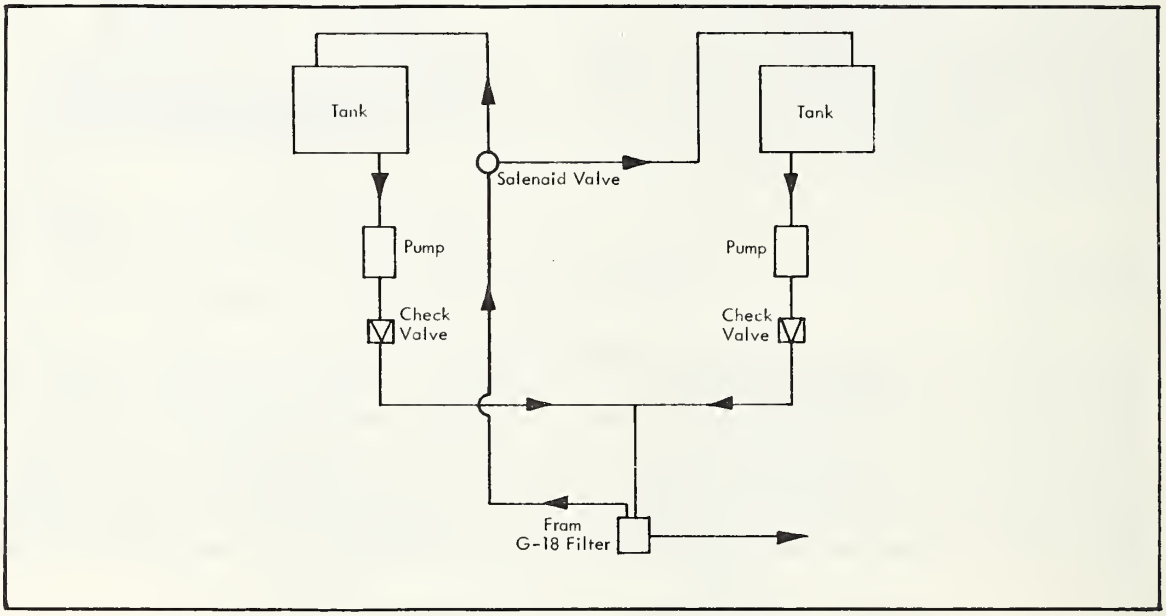

Figure 18. Prototype fuel supply system 3 as installed on Model 56, FS 1609.

Field Test Results - System 3

This tanker was equipped with two Bendix pumps, Model 476459 and 476087. The operator observed that Model 476087 was not of sufficient capacity to run the engine at sustained high loads for any appreciable length of time. Model 476459, although it does not pérform as well as the Carter, the AC, or the Stewart-Warner, apparently provided sufficient performance. The low output pump was replaced with a Model 476459. The Fram G-18 filter was opened and found to be lightly loaded after one year and 4,000 miles of use. Thus, it appears that the life of the filter units would be considerably greater than one year. The filters in the bottom of each pump were opened and inspected. Approximately 1/2 gram of foreign material was found in each. A two or threefold increase in this amount of contaminant could clog the

filters. Therefore, it is suggested that the pump filters, which act as primary filters in any of these fuel systems, should be cleaned at least annually and that special precautions be taken to insure that the fuel supply is clean.

SYSTEM 4 - IMPROVED SYSTEM UTILIZING MECHANICAL PUMP

System 4, employing the stock mechanical fuel pump, was installed on FS 394, a nurse tanker. An AC #97 fuel filter was used and gasoline feed and return were switched with ganged 2-way valves. Cadmium plated 5/16-inch line was used. Figure 19 shows the system schematically. Figure 20 shows the method used to gang the valves.

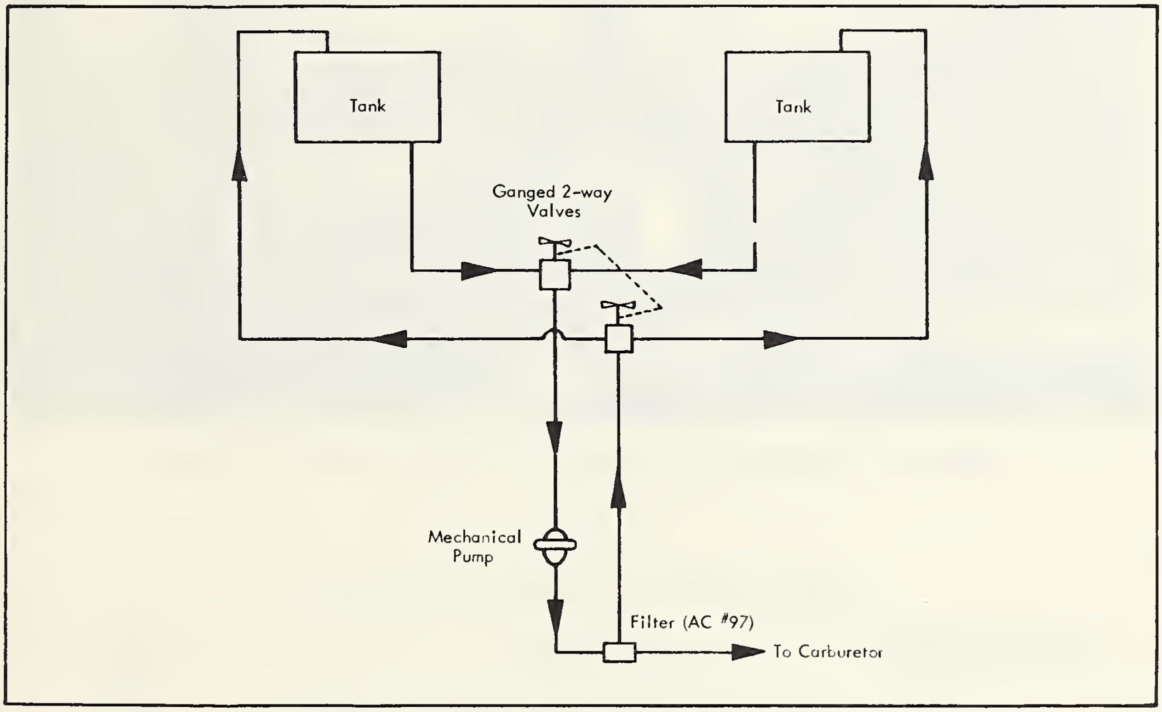

Figure 19. Prototype fuel supply system 4 as installed on nurse tanker.

This system was found to function in an entirely satisfactory manner and no vapor lock was experienced. It does not have the inherent reliability of systems using electrical pumps but provides performance superior to stock equipment at a price significantly lower than the more complete systems installed on the three crew tankers. Although a complete fire season surveillance has not been carried out, up to this time it appears to be satisfactory.

COST CONSIDERATIONS

The installed costs for systems similar to the four prototypes is shown in table 5. Also shown are a bypass system using one electric pump and a mechanical pump system for use with light vehicles with one fuel tank. The other estimates assume that two gasoline tanks are used. This is the case in virtually all trucks of over 10,000 pounds GVW.

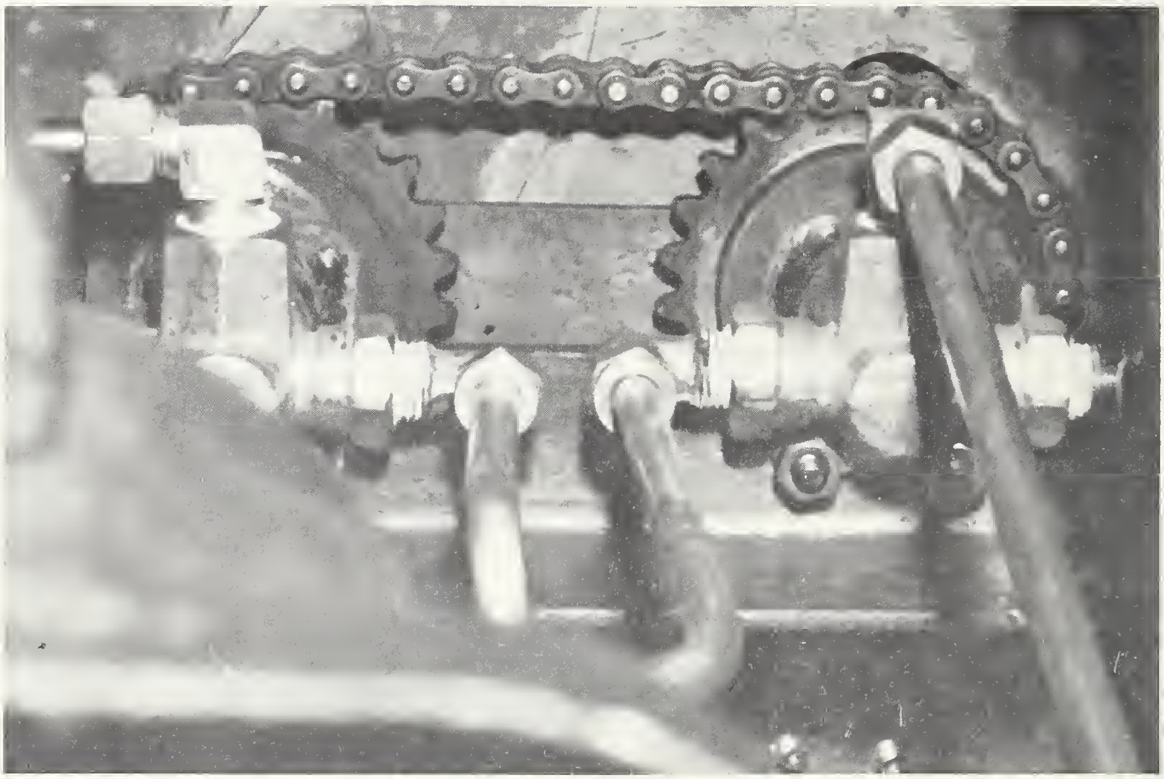

Figure 20. Method used to gang two 2-way valves on FS 394.

TABLE 5

Cost of vapor lock resistant fuel systems

System Number	Description	Cost
1 (Improved)	2 electric pumps, bypass filter, manual return line switching (recommended system) (see figure 22)	$222
2	2 electric pumps, bypass filter, automatic fluidic return line switching (not recommended)	226
3	2 electric pumps, bypass filter, electric return line switching	186
4	Mechanical pump, bypass filter, manual return line switching	133
	1 electric pump, bypass filter, manual return line switching	173
	Mechanical pump, bypass filter (one fuel tank)	43

OTHER APPROACHES TO THE VAPOR LOCK PROBLEM

Other equipment for eliminating fuel system malfunctions in crew tankers has been used. One is the installation of a fuel injection system on a tanker ordered by the Angeles National Forest. This system appears to be completely effective in eliminating the fuel supply problems, and it does provide a 10 percent increase in engine power. However, it has the disadvantage of being quite expensive, approximately $2,000.

A second approach, used extensively by the California Division of Forestry, is the use of submerged in-tank electric fuel pumps. In addition to being rather expensive (about $60 per tank for the pump only, not including installation), these pumps are quite inaccessible for maintenance. They are not really suitable to retro-fit on existing tankers, nor are they available for tanks of other than the "saddle" (external side-mount) type. They have not always been completely effective in eliminating vapor lock, but are a great improvement over engine-mounted diaphragm pumps.

CONCLUSIONS

1. It is possible to eliminate virtually all vapor lock and hot stall by careful design and installation of the fuel systems.

2. The vapor lock and hot stall resistant systems require no extraordinary precautions other than careful handling of the fuel.

3. System cost ranges from less than $50 for small vehicles to about $200 for a complete system for large trucks with two-fuel tanks.

4. Use of a simple bypass, such as shown in figures 19 or 21, will eliminate most vapor lock and hot stall.

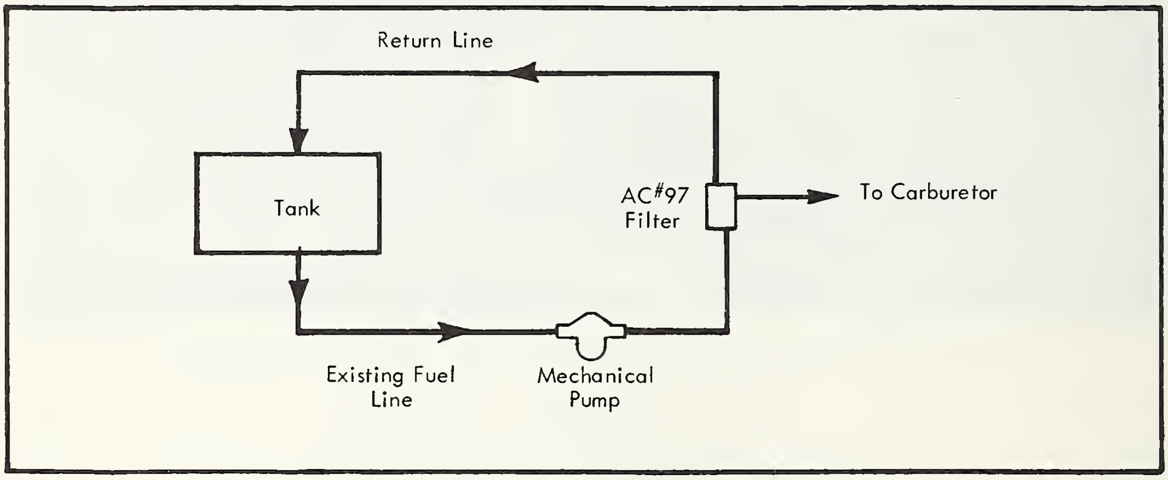

Figure 21. Step 1 fuel system - light vehicles.

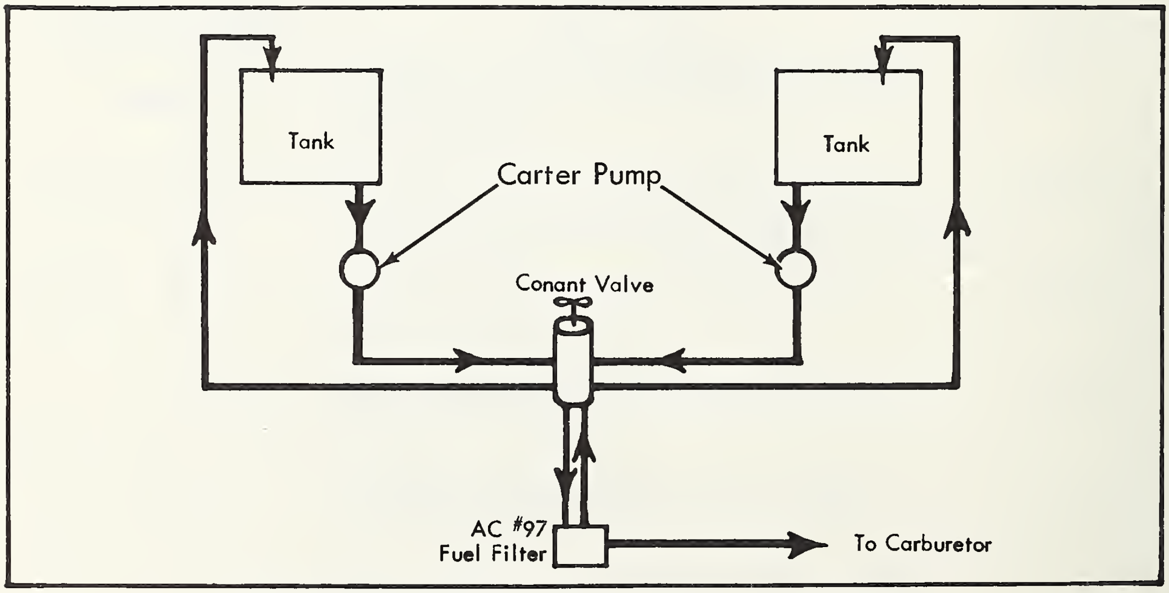

Figure 22. Complete fuel system - heavy vehicles.

5. The optimum complete system for heavy vehicles consists of the components shown in figure 22 and table 6.

Table 6.--Recommended fuel system component list

Quantity	Description	Approximate retail price
2	Carter Fuel Pump (Model no. depends on voltage and polarity)	$30.00
1	AC #97 Fuel Filter or equivalent	2.00
1	Conant BR2TSL Valve	50.00
As required	Weatherhead 5/16 i.d. hose or equivalent	.50/ foot
As required	Cadmium-plated steel line, 5/16 o.d.	.35/ foot
As required	Compression fittings, Imperial Eastman or equivalent	.25 ea.

RECOMMENDATIONS

1. The first step in eliminating vapor lock and hot stall should be the installation of a bypass.

2. If further vapor lock or hot stall are encountered, a more complete system, such as the one shown in figure 22, should be installed.

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APPENDIX

COST ESTIMATES OF VAPOR LOCK RESISTANT FUEL SUPPLY SYSTEMS

All for a tanker with two gasoline tanks.

Labor charged at $8.00 per hour.

System 1 (Improved) - Two electric pumps, bypass filter, manual return line switching.

Parts

30 feet 5/16-inch steel tubing	$ 10.00
Fram G-18 filter	2.00
2-way valve (Conant BR2TSL)	50.00
2 electric pumps	60.00
Clamps, hose, and fittings	20.00

Labor

Remove tanks, attach return line fittings, replace tanks - 4 hours	$ 32.00
Install lines and brackets - 4 hours	32.00
Install pumps - 2 hours	16.00
Total	$ 222.00

System 2 - Two electric pumps, bypass filter, automatic fluidic return line switching.

As for System 1, plus $34.00 for Miller fluidic instead of $14.00 for solenoid valve, and $20.00 for additional labor, fittings, and tubing.

Total $ 262.00

System 3 - Two electric pumps, bypass filter, solenoid return line switching.

As for System 1, plus $14.00 for solenoid instead of $50.00 for 2-way valve.

Total $ 186.00

System 4 - Mechanical pump, bypass filter, manual return line switching (System #1).

Parts

20 feet 5/16-inch steel tubing	$ 7.00
Fram G-18 Filter	2.00
2-way stacked valve	50.00
Clamps, hose, and fittings	10.00

Labor

Remove tanks, attach return line fittings replace tanks - 4 hours	$ 32.00
Install lines and brackets - 4 hours	32.00

Total	$133.00

One electric pump, bypass filter, manual return line switching. As for System 4, plus $30.00 for pump and $10.00 for additional fittings and installation labor.

Total	$173.00

Mechanical pump, bypass filter, one tank system.

Parts

10 feet 5/16-inch steel tubing	$ 4.00
Fram G-18 Filter	2.00
Clamps, hose, fittings	5.00

Labor

Remove tank, attach return line fitting, replace tank - 2 hours	$ 16.00
Install line and brackets - 2 hours	16.00

Total	$ 43.00